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Functional Requirements for Continuation Period Equipment and Drilling

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FUNCTIONAL REQUIREMENTS FOR CONTINUATION PERIOD EQUIPMENT AND DRILLING

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NOTE TO READER: This paper, to include any proposed language for the OSI Operational Manual, is a contribution of the individual expert and not a national contribution of the United States

Fundamental concepts:

For geophysical measurements, creating a functional requirement based on finding a specific-sized target at a specific depth is difficult because of the wide variation of subsurface and surface geologic conditions that can be encountered. An alternative approach used in this paper is to specify functional requirements based on what is needed to search for the effects of a given target within a reasonable background of environmental or geological variation (noise).

There is a gap between what the state-of-the-art expert with a large amount of experience can be expected to accomplish and what a non-expert inspector with limited experience can do. There are also limitations because of the Treaty environment (equipment certification, transparency, managed access, etc.); thus, for OSI, we must opt for a pragmatic approach.

Equipment must be easy to use, rugged, and functional over a wide range of environmental conditions.

Equipment should consist of commercially available technology.

Well-established operational procedures should be used for taking measurements, reducing data, and presenting data, with software mostly provided by the manufacturer along with the equipment.

Equipment should be used in conjunction with WGB-approved position-finding equipment capable of relative position determinations pertinent to the type of equipment and measurement.

Use of software for interpretation, such as forward modeling (calculating a model to compare with data) or inverse modeling (calculating a model based on the data), is to be determined.

The objective is to look for the most obvious anomalies that would be associated with an underground nuclear explosion. Extra efforts (beyond a standard, well-established, normal industry practice approach) to reduce noise (instrument noise, or noise due to variations in the geology) belong to the realm of state-of-the-art researchers and should be avoided.

Features of the data acquired with different equipment complement each other (synergy) and provide added confidence in the interpretation of the results.

The efficiency and effectiveness of any geophysical surveys will be enhanced by the use of any existing regional magnetic, gravity, geologic, and terrain (elevation) data.

Technologies:

Additional overflight:

Note: For all overflight equipment, it will be important to obtain simultaneous video of the ground along the flight path while the instruments are recording. When the data is analyzed, this video will be used to associate any anomalies in the data with possible visual features on the ground. Flight path orientation (position, altitude, ground speed) and other environmental variables, such ambient temperature at the instrument, need to be recorded and synchronized with the measured data. There are specific requirements on the accuracy required for location and altitude with each technology. If possible, the equipment should be designed to be easily fitted to a wide variety of aircraft types. NOTE: Although additional overflight equipment is covered in this paper for the continuation period, it does not preclude the use of the agreed techniques during an additional overflight in the initial period of inspection.

Multi-spectral imaging (including infrared) [Protocol, Part II, paragraph 80]:

The objective is to look for spatial variation in an image response at various wavelengths over a wide spectral band, including infrared, of images of the earth's surface from a slow-moving aircraft. Targets for detection are spatial emissivity changes over small distances due to shallow-buried artifacts or surface changes due to recent equipment operation or facility construction. Over broad areas (tens to hundreds of meters), targets will be changes in surface materials or plant stress due to spall or other surface effects from an underground explosion. At a minimum, the equipment should be capable of recording images in the ultraviolet (.3-.4 μm), blue (.4-.5 μm), green (.5-.6 μm), red (.6-.7 μm), near infrared (.7-1.0 μm), short-wave infrared (1.0-3.0 μm), and thermal infrared (3.0-15.0 μm) bands with data retrieval rates equal to or exceeding video. Bandwidth for a particular imaging band should be less than 15% of the wavelength recorded. For imaging plant stress, however, the equipment should record the 0.69 μm and 0.42 μm wavelengths with bands no wider than 0.03 μm. Also desirable would be measurements of green plant reflectance at 0.54 μm with a 0.03 μm bandwidth and discrete measurements in the near infrared at 0.75 and 0.85 μm with a 0.05 μm bandwidth. The minimum, instantaneous field-of-view of the instrument should be no greater than 1 m at a 500 m elevation (a 2 mrad aperture) and have at least 8 bits of dynamic range. This will result in an image resolution of 60-100 cm when the instrument is at an altitude of 500 m. The far infrared imagery should be accomplished with a separate camera, as is typically done with commercial equipment. The equipment must be mounted in the aircraft so that infrared images are not acquired through window glass. Imagery will be compared to ground-based and aerial visual photography and human observational experience to eliminate associated obvious effects due to known cultural features or geology.

Aerial gamma spectroscopy [Protocol, Part II, paragraph 80]:

The objective is to scan the earth's surface from an aircraft to detect regions of elevated gamma radiation due to human activities. The system will consist of a broadband system with low resolution, such as a sodium-iodide detector, that has only very limited capability for identifying individual radioisotopes. At a minimum, the equipment should span a spectrum of 70-1600 KeV with 512 channels and a sampling time faster than 2 seconds using a sodium-iodide detector of 16-32 liter volume. The system should be capable of detecting an equivalent point source of ^{137}Cs or ^{241}Am at levels of tens of Bq/kg. In the data processing, windowing should be available to determine the energy contributions from ^{40}K and the ^{238}U-^{232}Th series for identifying background level variations.

Aerial magnetic field mapping [Protocol, Part II, paragraph 80]:

The objective is to identify, from an aircraft survey, large magnitude, spatially limited magnetic anomalies related to buried ferrous objects such as drill pipe or drill-hole casing and shallow-buried (less than 10 m) metal artifacts, etc. Variation in the local magnetic field due to geology can be hundreds of nT (a nanotesla = 1 gamma) or more over distances of hundreds of meters to kilometers. An anomaly will be a change in total magnetic field of more than 1000 nT over distances less than 100 m. The equipment should be able to measure total magnetic field strength over a range of 30,000 to 100,000 nT with a 0.1 nT accuracy with high stability at sampling rates of one second or faster. When carrying out any magnetic survey, a second magnetometer must be used to measure diurnal variation of the magnetic field variation at a fixed location near the survey site; thus a minimum of two instruments will be needed for an OSI.

Other continuation period technologies:

A common element of continuation period geophysical investigations is a need for an accurate determination of the location of measurement profile lines and measurement points. Individual measurement points should be located with a relative accuracy (lateral and vertical) of about 0.1 m over distances of 1-3 km. Gravity measurements will require sub-centimeter (millimeter) precision for relative elevation measurements. Standard survey equipment or GPS units, in differential mode, should be used to carry out the surveys.

Resonance seismometry [Protocol, Part II, paragraph 69f]:

The objective is to measure the spatial variation in near-surface seismic wave propagation, along near-vertical paths from distant sources, that may be caused by an underground rubble chimney, explosion cavity, or excavated cavity due to an underground explosion. The method is directed towards features less than 5 km in depth and uses distant seismic waves from distant events to illuminate the zone from below. A cavity could be 30-50 m in diameter and located from 100 to 500 m or more beneath the surface. The equipment to be used for resonance seismometry is the same as that employed for passive seismic surveys during the initial period of an OSI, but some additional data processing software will be used. The software will be capable of analyzing subtle differences between waveforms of compressional, shear, and other seismic phases as measured from a common distant seismic event on closely-spaced (tens of meters separation) seismometers.

Active seismic methods [Protocol, Part II, paragraph 69f]:

The objective is to use a controlled seismic source and a linear array of geophone receivers to detect the presence of an explosion cavity, excavated cavity, or fractured and rubble chimney zone (tens of meters in diameter and up to several hundred meters in vertical extent). Active seismic methods determine spatial changes in the properties of seismic wave propagation; these must be interpreted to understand the structure. A cavity could be 30-50 m in diameter and located from 100 to 500 m or more beneath the surface. [Geophones should detect frequencies up to 200 Hz and the system should employ sampling rates of 1000 Hz or better. The active seismic source is typically a truck vibrator, explosives, or perhaps a dropped weight. The entire source, data collection system, and data processing system should be easy to deploy under a wide range of conditions.

Magnetic field mapping [Protocol, Part II, paragraph 69g]:

The objective is to identify, from a ground-based survey, large magnitude, spatially limited magnetic anomalies related to buried ferrous objects such as drill pipe, drill-hole casing, shallow-buried metal artifacts, etc. Variation in the local magnetic field due to geology can be hundreds of nT (gammas) or more over distances of hundreds of meters to kilometers. An anomaly will be a change in total magnetic field of more than 1000 nT over distances less than 100 m. The equipment should be able to measure total magnetic field strength over a range of 30,000 to 100,000 nT with a 0.1 nT accuracy with high stability at sampling rates of one second or faster. When carrying out any magnetic survey, a second magnetometer must be used to measure diurnal variation of the magnetic field variation at a fixed location near the survey site; thus a minimum of two instruments will be needed for an OSI. The equipment should be portable with a device to insure that each measurement is taken at one or more common, known, elevations relative to the earth surface.

Gravitational field mapping [Protocol, Part II, paragraph 69g]:

The objective is to identify, from a ground-based survey, large magnitude, spatially limited gravitational anomalies related to buried masses with a positive density contrast to surrounding material, such as grout-filled drill casing or buried artifacts. An additional objective would be to detect subtle, spatially limited, negative gravity anomalies related to apical voids above a rubble chimney or large underground excavated cavities. The need to make terrain corrections to gravity data requires sub-centimeter precision elevation surveys. Natural variation of the gravitational field is on the order of tens to hundreds of mgal over distances of hundreds of meters. The measurement equipment must be capable of tens of μgal precision and stability over a range of temperatures. Gravitational anomaly data is best interpreted in conjunction with results from the other methods listed in Protocol, Part II, paragraph 69, especially magnetic field mapping.

Ground penetrating radar (GPR) [Protocol, Part II, paragraph 69g]:

The objective is to detect shallow, spatially limited subsurface changes in radar reflectance related to buried artifacts, faults, or large fractures covered by soil. To achieve depth of penetration of radar energy to 10-20 meters for a large range of subsurface conditions, a system using a variety of frequencies should be used. This will require a system with 5-6 antenna sets covering a frequency range of 20-900 MHz with the highest power output that is available. The equipment should include an integrated workstation with software capable of creating time section displays. GPR data is best interpreted in conjunction with results from other methods such as magnetic field mapping and electrical conductivity.

Electrical conductivity measurements [Protocol, Part II, paragraph 69g]:

There are two different objectives for this technology and each requires different equipment. One objective is to detect shallow, spatially limited subsurface changes in electrical conductivity related to buried conductors or other metallic artifacts. The second objective is to detect a subsurface change in electrical conductivity related to an explosion cavity, excavated cavity or rubble chimney from an underground explosion. The cavity or rubble chimney may be located several hundred meters deep, with a diameter of a few tens of meters. Most likely, the resistivity contrast will be positive, unless the cavity is filled with saline water, when it will be highly negative. To minimize intrusiveness and allow for simplified operations, controlled-source time domain electromagnetic methods are preferred. For shallow (1-50 m) depth investigations, a portable battery-powered induction field ground conductivity instrument capable of 0.1% precision at full scale over ranges of ±10, ±100, ±1000 mS/m (1 milliseimen/meter is equivalent to 1000 ohm-m) is preferred. For deep (50 m – 2 km) investigations, the equipment should be capable of performing controlled source audio frequency magnetotelluric or transient electromagnetic measures with a high-power (several kilowatts) generator and controller. This equipment should be capable of operating over frequencies of 0-8 kHz in sounding or profiling mode. Data from shallow subsurface changes will best be interpreted in conjunction with results of GPR and magnetic field mapping surveys; data from deep targets are best interpreted with results from active seismic or resonant seismic surveys.

Drilling [Protocol, Part II, paragraph 69h]:

The objective is to safely drill into or close to an explosion cavity and retrieve samples for radiological analysis. The equipment should be capable of directional drilling to depths/distances of up to a 2 km with an accuracy of 10 m, rapid drilling rates in hard rock, and measurement of high levels (10,000 to 60,000 counts per second—minimum 50 times the background) gamma radiation near the drill bit while drilling. An easily transported system capable of drilling from inside a mine or tunnel as well as from the surface is preferred. Because subsurface steam pressures may be encountered, the system must include blow-out protection for safety and environmental concerns and to prevent surface release of radioactivity.